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THE HYDROGEN ION AND ASH OF HUMAN SWEAT PRODUCED BY HEAT AND WORK

A DISSERTATION

SUBMITTED TO THE FACULTY
OF THE OGDEN GRADUATE SCHOOL OF SCIENCE
IN CANDIDACY FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

DEPARTMENTS OF PHYSIOLOGY AND ZOOLOGY

BY

GEORGE ADDISON TALBERT

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EFFECT OF WORK AND HEAT ON THE HYDROGEN ION CONCENTRATION OF THE SWEAT

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INTRODUCTION

Early in the year 1918 my attention was attracted to some work that had been done several years ago demonstrating, incidentally, how muscular fatigue might affect the reaction of the urine. The fact that the results were conflicting, and particularly that all the investigators used methods of titration, which we now recognize as quite unreliable for obtaining total acidity, led me to think that this might prove an interesting field for research. Furthermore, inasmuch as the literature seemed to be silent as to whether exercise in any way affected the reaction of the sweat, it seemed to be desirable to make determinations on the urine and sweat simultaneously, with the subject under the same conditions, with the view first, of establishing more definitely the results of the earlier observers as far as the urine was concerned; second, to ascertain if any reaction changes occur in the perspiration; and third, whether these changes, if they occur, show either a supplementary or a compensatory relationship with the urine.

With these ideas in mind I made a few preliminary tests in Ripon College chemical laboratory through the courtesy of Dean Barber and Professor Barker. However, the problem was not attacked in an intensive manner until I had the privilege of pursuing the work during the school year of 1918-1919 in the physiological laboratory of Professor Howell in the School of Hygiene and Public Health of the Johns Hopkins University. It therefore seems most fitting that I should here acknowledge my deep gratitude to him for his helpful suggestions and above all the inspiration that I received from his kindly interest. In the same manner I wish to thank Doctor Spaeth of this laboratory for assistance with the experimental technique.

It is my purpose in this article to consider simply the perspiration, and to discuss subsequently the results obtained from the urine.

We have in the past been quite willing to assume that the principal function of the sweat glands is for the regulation of body temperature, and not much emphasis has been laid upon the significance of the composition of the excretion.

Before entering upon the discussion of the problem some of the views that have been held in the past as to the reaction of the sweat, more or less conflicting, may be stated briefly.

Foster (1) states that "Sweat from a well washed skin is alkaline. It is only when mixed with sebum that it is acid. Horses' sweat is said to be always acid." Smith (2) finds horses' sweat strongly alkaline. Moriggia (3) states that in herbivora the reaction is generally alkaline, while in carnivora it is acid. Gaube (4) speaks of the human sweat as acid, while that of the horse, cow, dog, cat and hog is alkaline. Certainly omnivora, herbivora and carnivora are found in this last list. In Landois' text (5) we find the statement that "swine sweat (?) on the snout, cattle about the mouth (?), while goats, rabbits, rats, mice and dogs do not sweat at all." Aron has stated that monkeys have no sweat glands but Shaklee (20) in later work reports that this is an error, "the skin seems everywhere provided with well-developed sweat glands."

METHODS

As has been suggested above, the criticism that may be made upon earlier work is concerned with the uncertainty of the data obtained by titration. In the observations which follow, use was made of the colorimetric and the gas chain methods in order to obtain the total acidity. As to the former, I followed mainly the method of Henderson and Palmer (6), which is an adaptation of the Sørensen method, while for the gas chain measurement I used a Leeds and Northrop's potentiometer with Clark's (7) hydrogen electrode shaker. It was hardly thought necessary to use a constant temperature chamber, but a thermometer was kept in the potassium chlorid vessel and therewith the corrections were made.

For the colorimetric method it may be stated briefly that there are required five standard solutions made up of monopotassium phosphate and disodium phosphate, mixed in such proportions that each solution will possess a distinct and definite pH value. In like manner, acetic acid and sodium acetate are so mixed as to give six standard solutions of

definite pH values. The former mixture is for use on the alkaline side with values ranging from 8.7 pH to about 7.0 pH. The latter reaches from 7.0 pH to 4.7 pH. These standards are as a rule made fresh once a week, but never kept longer than two weeks. When ready for tests, 4 cc. of each standard was taken and diluted with distilled water up to the mark in a 100 cc. flask, and a similar dilution was taken for the sweat. An equal amount of indicator added to the same volume of the diluted standard and the diluted sweat and the colors thereby matched gave a fair evaluation for the reaction of the latter even where interpolation was necessary.

As to the indicators, phenolphthalein can be used for values between 8.7 pH and 8.0 pH. Neutral red, however, is very useful between 8.0 pH to even below the neutral point 7.0 pH. Methyl red is excellent on the acid side from 5.7 pH to 4.7 pH, and is not affected by proteins, while p.nitrolphenol covers a wider range and is an excellent indicator between 6.7 pH and 4.7 pH. Sodium alizarine sulphonate covers the entire field from 8.0 pH to 4.7 pH, thereby meeting all of the variations that I have found in the perspiration. There were, at times, in use the indicators that are recommended by Clark and Lubs (8), which were quite satisfactory.

In the main the determinations were made by the colorimetric method, while the potentiometer was used for checking up the standard solutions.

Unfortunately the gas chain was not brought into use as often as one might wish, because at times tedious delays were caused by not being able to get the services of a mechanician.

I am aware that objections may be urged against placing too much reliance upon absolute evaluation by the colorimetric method. "Off-shades" did arise at times, especially with the use of sodium alizarine sulphonate. In that case determinations had to be made with other indicators or the test would have to be rejected.

The protein and salt errors have been long recognized by Sørensen and others. As to the former, I have a feeling that the per cent in the sweat is so low that its effects are quite negligible. As to the latter, I have not that same confidence, for the work of Viale (9) shows variations in the salt content. Of late some have laid considerable emphasis upon the variations due to the carbon dioxid factor.

However, after making due allowance for these liabilities to error it must not be overlooked that Lubs and Clark (10) and others have obtained some remarkable agreements in the two methods.

Granting that there might be some slight errors in the absolute, there can hardly be any errors in the relative values, as the samples to be compared were tested almost simultaneously.

My first tests were made on volunteers from the Baltimore Central Y. M. C. A. and upon a few of the workmen about the laboratory. These were hardly more than preliminary try-outs, as was ultimately proven. In some cases the skin was cleansed with water or alcohol, while in others not at all. The samples which were collected at the Y. M. C. A. were really the combination effect of heat and work, for the subjects, after playing basket-ball or volley-ball, as the case might be, came into the hot-room where the samples were obtained.

One important point revealed by these tests was that the sweat contains a greater concentration of hydrogen ions than one would naturally suppose.

However, the futility of the volunteer plan soon became apparent. It was evident that in order to make the experiments worth while it was necessary to have reliable and well selected subjects who would be willing to come to the laboratory, where it would be possible to have better controls. This end was realized by obtaining as subjects some medical students, who had a much better appreciation of the importance of the work and were willing to cooperate in a most excellent manner.

The few subjects that I used, mainly, were in perfect health, as they had passed the tests as donors of blood for transfusion cases. After undertaking the work in the laboratory my first thought was to ascertain if exercise produced any changes in the hydrogen ion concentration of the sweat. Consequently there arose the suggestion of a control.

My idea was to obtain heat-sweat first and then secure work-sweat immediately afterwards, with the feeling that if any change took place in the latter it would be as in the case of the urine in the elimination of more acid as a result of work.

The subjects were stripped and the parts from which the sweat was to be taken, viz., face, chest and abdomen, were first washed with soap followed by cleansing with water, ether and alcohol in the order named. In the application of the last two liquids dental napkins were used. The subjects were then placed in a hospital sweat-cabinet with a fair amount of moisture, starting with a temperature of about 30°C. and finally increasing it to 40° or 45°C. The heating lasted from fifteen to twenty-five minutes, according to the subject and the number of samples to be obtained. All samples of sweat were collected by means of lipless specimen tubes.

After this procedure, the parts being controlled as before, the subject was placed on a stationary bicycle where he worked for fifteen to twenty-five minutes. The samples of work-sweat and heat-sweat were then tested as soon as possible and comparisons were made.

The most striking thing about the data, in the securing of which there were sixteen observations upon six different individuals, was that in each instance the heat-sweat was of a greater hydrogen ion concentration than the work-sweat. (See table 1, series A.)

TABLE 1

HEAT PRECEDING WORK SERIES A				WORK PRECEDING HEAT SERIES B			
Subjects	pH heat-sweat	pH work-sweat	Difference	Subjects	pH work-sweat	pH heat-sweat	Difference
G.	5.4	5.9	0.5	G.	5.8	5.4	0.4
G.	5.5	5.65	0.15	G.	5.8	5.5	0.3
G.	5.25	5.8	0.55	G.	5.7	5.5	0.2
J.	5.8	6.4	0.4	G.	5.9	5.2	0.7
J.	6.4	6.6	0.2	G.	5.9	5.15	0.75
J.	5.4	7.0	1.6	J.	5.6	5.6	0.0
E.	7.2	7.5	0.3	J.	6.1	5.5	0.6
E.	7.1	7.4	0.3	E.	7.4	5.3	2.1
E.	6.0	7.4	1.4	F.	5.8	5.2	0.6
E.	5.6	7.4	1.8	C.	5.45	4.7	0.75
E.	5.7	6.5	0.8	S.	6.15	5.5	0.65
E.	5.7	6.5	0.8				
E.	5.6	6.8	1.2	6	5.96	5.32	Av. dif. 0.64
B.	6.2	7.4	1.2				
A.	5.6	6.0	0.4				
M.	5.1	5.9	0.8				
6	5.22	6.63	Av. dif. 1.41				

Fearing that the first excretions might be more acid due to the sebum or other causes, I reversed the process by producing work-sweat first. I made eleven observations with the use of six individuals, with the result that the heat-sweat was still of higher acidity. (Note table 1, series B.)

I next adopted the plan for a few experiments upon subject G. of producing sweat in the morning by work and by heat in the afternoon, and then reversed this process, with no particular differences in the results.

All of the remainder of the experiments were performed on two individuals simultaneously, one producing heat-sweat and the other work-

TABLE 2

TESTS	SUBJECTS	pH WORK	pH HEAT	AVERAGE DIFFER- ENCE	TESTS	SUBJECTS	pH WORK	pH HEAT	AVERAGE DIFFER- ENCE
1	G.	5.9	5.5		1	E.	7.5	7.2	
2	G.	5.65	5.4		2	E.	7.4	7.1	
3	G.	5.8	5.25		3	E.	7.5	7.2	
4	G.	5.8	5.5		4	E.	7.4	7.1	
5	G.	5.7	5.2		5	E.	7.4	6.0	
6	G.	5.9	5.0		6	E.	6.5	5.6	
7	G.	5.8	5.25		7	E.	6.5	5.7	
8	G.	5.7	5.5		8	E.	6.8	5.7	
9	G.	5.6	5.4		9	E.	7.4	5.6	
10	G.	5.8	5.4		10	E.		5.8	
11	G.	5.8	5.4		11	E.		5.3	
12	G.	6.0	5.85				7.15	6.24	
13	G.	5.6	5.6						
14	G.	5.6	5.6						
15	G.	5.8	5.4						
16	G.	5.8			1	J.	6.4	5.8	
17	G.	5.7			2	J.	6.6	6.4	
18	G.	5.35			3	J.	5.6	5.4	
19	G.	5.35			4	J.	6.1	6.4	
20	G.	5.9			5	J.		5.8	
					6	J.		5.2	
		5.73	5.42	0.31			6.18	5.83	0.35
1	M.	5.1	5.1						
2	M.	5.4	5.4						
3	M.	5.95	5.85						
4	M.	5.65	5.6						
5	M.	5.8	5.6						
6	M.	5.8	5.4						
7	M.	6.4	5.8						
		5.84	5.54	0.30					

TABLE 3

OBSERVATION	SUBJECTS	pH WORK	OBSERVATION	SUBJECTS	pH HEAT
20	G.	5.73	15	G.	5.42
7	M.	5.84	7	M.	5.54
9	E.	7.15	11	E.	6.24
4	J.	6.18	6	J.	5.83
13	X.	6.19	14	X.	5.61
Total 53		Av. 6.22	Total 53		Av. 5.73

TABLE 4

SERIES A HEAT-SWEAT pH				SERIES B WORK-SWEAT pH		
Subjects	First sample	Second sample	Third sample	Subjects	First sample	Second sample
G.	5.5	5.6		G.	5.7	5.8
G.	5.5	5.65		G.	5.6	5.65
G.	5.2	5.45		G.	5.8	5.9
G.	5.12	5.2		G.	6.0	5.8
G.	5.0	5.2		G.	5.6	5.55
G.	5.25	5.3	5.5	G.	5.8	5.6
G.	5.5	5.55	5.6	G.	5.7	5.9
G.	5.4	5.55	5.55	G.	5.9	5.8
G.	5.85	5.15		G.	5.35	5.3
G.	5.6	5.45		G.	5.7	5.75
G.	5.6	5.3		G.	5.9	5.95
G.	5.4	5.45		G.	5.9	5.6
G.	5.4	5.5		G.	5.65	5.7
G.	5.5	5.6		G.	5.8	5.75
G.	5.25	5.2				
M.	5.4	5.15	5.5	M.	5.5	5.8
M.	8.0*	5.2	5.25	M.	5.95	5.15
M.	5.85	5.8		M.	5.65	5.9
M.	5.6	5.35		M.	5.8	5.85
M.	5.4	5.25		M.	5.8	5.4
M.	5.8	5.6	5.8	M.	6.4	6.3
M.	5.1	5.2	5.4	M.	5.9	5.8
				M.	5.8	6.0
E.	5.9	5.7				
E.	5.4	5.25				
F.	4.85	4.7	5.1			
S.	5.35	5.7	5.8			
J.	5.2	5.35	5.3			
O.	5.9	5.7				

* This unusual reading may be due to the fact that the subject had served as a donor in a blood transfusion three hours before the experiment.

sweat, while the next day the performance was reversed. The grand totals from these experiments are given for four of the subjects in table 2.

Table 3 gives averages of the four principal subjects, while X. represents the average of several individuals taken together where not more than one or two tests were made on each person.

In table 4, series A, are found twenty-eight experiments in which two samples of heat-sweat were taken, while in series B of the same table we have twenty-two experiments in which two samples of work-sweat were taken. It is a remarkable coincidence that just 50 per cent of the second samples increased in acidity in both kinds of experiments.

There were ten tests in which three samples were taken successively as a result of heat. Comparing the third with the first sample we now find that eight are less acid, while one is more acid and one remains the same. In comparing the third with the second sample we again find that eight are less acid, one is more so, while one remains the same. The skin was cleansed as before after each collection, and an interval of five minutes elapsed between the collection of the successive samples.

CONCLUSIONS

In my conclusions I wish to emphasize that in many cases the changes were exceedingly small, yet the distinction was always obvious. Furthermore it is to be remembered that the work experiments were not long-enduring and fatiguing tests like those that have been reported in the past on the urine. On the contrary the subjects as a rule had performed their part of the experiments within one hour. While the time was short, the experiments, especially from exercise, were rather intense. In a majority of cases these tests took place late in the forenoon, ranging from two to five hours after a meal.

The work reveals the following facts:

First, that sweat caused from either work or heat is acid, probably always so in perfect health, and the degree of acidity is greater than we have heretofore believed.

Second, in a continued secretion of sweat the reaction does not remain entirely constant. A second sample may show a slight increase or decrease in acidity, while a third sample shows practically in all cases a small but distinct diminution compared with the first sample.

Third, the sweat caused by external heat is always more acid than that caused by muscular work.

Many authors have assumed that the secretion of sweat is normally alkaline and that the acid reaction actually shown in many cases is due to admixture with sebaceous secretion. But Francois-Franck (11), Kittsteiner (12) and others, state that the sweat from the palm of the hand is acid, although this portion of the skin is devoid of sebaceous glands. The observations reported in this paper also throw doubt upon this explanation of the acidity of sweat as usually collected, since the precautions taken to cleanse the skin before collecting the sample should have been sufficient to remove any deposit of sebaceous material. The immediate cause of the acidity of sweat has not been determined satisfactorily. Halliburton (13) states that the sweat, like the urine, contains acid phosphates, but this explanation has not been corroborated by satisfactory analyses. Others have assumed the presence of volatile fatty acids in the secretion, and some observations of my own tend to support this view. In a number of cases the insensible perspiration was collected by fixing a finger suitably in a glass chamber, so that the vapor would condense upon the walls of the vessel. When diluted and compared with distilled water this condensate gave always an acid reaction. Aubert (14), Röhig (15), Schierbeck (16), Fubini and Ronchi (17), have emphasized the importance of carbon dioxid. The amount of carbon dioxid excreted varies with exercise and especially with external temperature. Schierbeck, for example, found that at a temperature of 29.8°C. there was an elimination of 8.9 grams of carbon dioxid in twenty-four hours, while at a temperature of 38.4°C. the amount excreted in the same period was 29.5 grams. The larger excretion of carbon dioxid would increase the acidity of the sweat as secreted, but presumably this factor did not enter into the reactions as determined by the method described in this paper. In these determinations the diluted specimens were exposed freely to atmospheric air, and presumably took on a corresponding tension of carbon dioxid.

The statement of Heuss (19), "*Der schweiss reagirt in der Ruhe normaler weise sauer bei profuser secretion (Pilocarpin, Schwitzbäder) kann er neutral ja sogar alkalisch werden,*" I could hardly support unreservedly. So far I have not tested any sweat produced by drugs, so I have nothing to offer on that point. However, when I have followed work with heat I have found that the sweat from the latter is not only more acid, but more profuse.

So the question of the profuseness, so often referred to in the literature, does not in itself offer a satisfactory explanation of differences in reaction.

The fact that heat-sweat shows uniformly a higher hydrogen ion concentration than work-sweat is surprising and contrary to expectation. In muscular work there is a large increase in the acid products of metabolism, and the output of acid in the sweat can be understood as part of the mechanism for preserving the acid-base equilibrium of the body. In heat-sweat we have heretofore regarded the secretion and evaporation of the water as an important means of controlling the body-temperature, the so-called physical regulation of the heat-equilibrium of the body. The fact that this heat-sweat is acid may be looked upon as a demonstration that the sweat in man under ordinary dietary conditions is normally acid, and that this secretion, like that of the urine, helps to maintain the acid-base equilibrium of the organism. But why the heat-sweat should exhibit a greater acidity than the work-sweat is not clear. It is hoped that further study of this problem may prove not only of physiological, but of therapeutical value.

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FURTHER STUDIES ON THE HYDROGEN ION CONCENTRATION OF HUMAN SWEAT

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Historical. What little work has appeared in the literature in regard to the reaction of the sweat seems to be mainly simple qualitative tests. In fact, Kittsteiner (1) was the first to determine the acidity by titration.

The reports of different investigators have been conflicting and even confusing where litmus paper has been employed. Favre (2) and some years later Trümper and Luchsinger (3) reported that the sweat was normally alkaline. Camerer (4) and Argutinsky (6) obtained variable reactions, while on the other hand Heuss (5) and Kittsteiner maintained that the sweat was normally acid.

The work on animals seems to have been confined mainly to the sweat of the horse and the sweat produced on the cat's paw by electrical stimulation of the sciatic. The former has been particularly studied by Moriggia (7), LeClerc (8), Smith (9) and Pugliesse (10) all of whom agree that only alkaline reaction can be obtained.

Trümper and Luchsinger and more recently Kittsteiner have made more serious attempts to ascertain the reaction of human sweat.

The former investigators seemed to be impressed with the idea that as normally secreted the sweat was alkaline, in support of which they have cited an experiment in which the palm of the hand was cleansed with ether and tested with litmus paper, with the result that the first secretion was alkaline, then a little later acid, due, as they claimed, to fat decomposition. While no sweat glands are found here, they very discreetly urged that under certain fixed conditions the sweat glands might function after the form of the sebaceous glands. Such claims, however, must be treated as a mere hypothesis and lacking in substantial support.

On the other hand, Kittsteiner reported results quite to the contrary. He maintained that when we had a weakly acid sweat it was only with difficulty that it could be transformed to alkaline, and this change he

claimed was due to bacterial decomposition. In support of his views he took samples of sweat in closed vessels and placed them in an incubator at 37°C. and found that the sweat was still acid after twenty-four hours, and it was two days before it became neutral and six days before it became alkaline, at which time the sample exhaled an unpleasant odor.

Both of these sets of investigators agreed that the sweat was eventually alkaline. There is this difference, however: Trümpy and Luchsinger claimed that the sweat is alkaline in the very act of secreting, while Kittsteiner maintained that it is never secreted alkaline but that the transformation takes place upon standing. Here we find a decided difference in opinion as to the time when the sweat is alkaline and, what is more to the point, as to the causes of the alkalinity.

It resolves itself to a point of interpretation as suggested by Trümpy and Luchsinger; that either we must be dealing with a normal alkaline secreting sweat that becomes acid due to fatty decomposition of the sebaceous secretion or we have a normal acid secreting sweat which only becomes alkaline due to ammonia formed by urea decomposition.

The first alternative is according to the ideas of Trümpy and Luchsinger, the second is that of Kittsteiner.

Whichever theory we accept there is one advantage that Kittsteiner had over all the other investigators: he attempted to determine the acidity by quantitative methods.

Experiments.—In the present work I followed the same method of acidity determination as reported in my first paper (11). The skin was always well cleaned with soap followed by distilled water, ether and alcohol applied with dental napkins. With these precautions I almost without exception obtained an acid-reacting sweat from practically all parts of the body. So by more modern methods and over one hundred tests my results verify those of Kittsteiner and others who maintained that the sweat is normally acid.

In my earlier experiments I found unexpected results, in that the sweat secreted as a result of heat gave a higher acidity than that secreted by work.

In all of these experiments the subjects were naked. The sweat produced by work was by the use of a stationary bicycle in a room at a temperature from 25°C. to 30°C. The heat sweat was produced while the subject was enclosed, except his head, in an ordinary sweat cabinet. The heat was generated by a household electric heater over which was supported a photographer's developing pan containing water for the purpose of producing humidity. The average temperature inside the cabinet was about 40°C.

It was through the suggestion of Professor Carlson that I commenced a series of experiments to ascertain, if possible, the cause of the difference between the hydrogen ions of heat and work sweat.

My problem was to find out whether the sweat glands, in their act of secreting, were actually eliminating more acid by heat than by work or whether it were possible that the very environment of the body, excluding temperature, might be the all-important factor, as the lack of ventilation and the higher humidity of the cabinet compared with the subject working in a large well-ventilated room.

In order to meet these factors it became necessary to contrive a means by which the parts of the body from which the sweat was to be collected should be under the same environmental conditions, as near as possible, except temperature, when acquiring both the heat and the work sweat.

To this end a rubber jacket was so constructed that there would be a hole at the top for the passage of the head, small enough when on to fit snugly around the neck, and likewise was so constructed that it would fit tightly around the waist and upper part of the arms so that part of the body would be enclosed fairly air-tight. The lower border of the jacket was tucked in all of the way around so as to make a trough for the collecting of the sweat. The trough was inclined ventralward on either side in order to cause the sweat to flow into a large test-tube which had been inserted in an opening in the trough. With this method it was not uncommon to collect 50 cc. in less than a half-hour.

A sleeve jacket for the arm was constructed on the same general plan, fitting tightly at each end so as to exclude the air but not to compress unnecessarily the blood vessels. A like jacket was used for the leg. So it was possible to collect sweat from three enclosed parts of the body independently at the same time, and even from an uncovered part as the face or the other arm or leg, as the case might be. So in each experiment it was possible to collect from two to four samples from as many parts of the body with simultaneous sweating. Instead of using the sweat cabinet, as I had previously done for the heat-sweat experiments, the subject occupied a large drying oven where the ventilation was better and proved to be more comfortable.

For the work I used a stationary bicycle which was so geared that it would register miles. While I was not able to ascertain the absolute amount of work the subject did, I was aware of the relative amount as he pedaled for each experiment the same number of miles in the same time, which was six miles in about twenty-five minutes. The work, however, was much more fatiguing than would be the case on an ordinary bicycle traveling on the level through the same distance.

If under these conditions we consult table 1 we will discover that the sweat was collected simultaneously from four parts of the body, viz.: bare face, covered chest, covered arm and covered leg, by means of heat. In table 2 the same parts of the body were employed, but the sweating was the result of work.

These figures show very definitely that the disparity which had been so noticeable hertofore between heat and work sweat as to acidity has now practically disappeared.

The face which gave an average 5.99 pH from heat gave 5.94 pH from work. The covered chest gave an average pH of 5.72 from heat and exactly the same from work. The covered arm yielded an average pH of 5.71 from heat and a pH of 5.73 from work. The covered leg as the result of heat gave a pH of 5.51 and as the result of work a pH of 5.48.

TABLE 1
Heat sweat pH values

FACE	COVERED CHEST	COVERED ARM	COVERED LEG
5.9	5.3	5.33	5.1
5.9	5.75	5.7	5.5
6.0	5.8	5.8	5.7
6.1	5.85	5.8	5.6
6.2	5.85	5.8	5.6
5.9	5.7	5.7	5.5
6.0	5.8	5.8	5.6
5.99 av.	5.72 av.	5.71 av.	5.51 av.

TABLE 2
Work sweat pH values

FACE	COVERED CHEST	COVERED ARM	COVERED LEG
5.9	5.7	5.75	5.5
6.2	6.0	6.0	5.8
6.0	5.8	5.6	5.5
5.7	5.5	5.0	4.8
5.9	5.6	5.45	5.3
5.94 av.	5.72 av.	5.56 av.	5.48 av.

In table 3 are results from samples collected simultaneously from the covered arm and covered leg, and we note here again a marked uniformity as shown for the arm an average of 5.50 pH from heat and 5.58 pH from work. From the covered leg in both instances we obtained the same pH average of 5.39.

In table 4 are given the results of the bare face and covered chest. The average pH value of the face is 5.99 from heat, while the average from work is 6.07. The chest yielded from heat an average of 5.68 and 5.55 from work.

These tables show a remarkable closeness in averages from the heat and work sweat. Even if there is any difference in the averages it is as apt to fluctuate one way as the other.

In table 5 are the results of entirely heat-sweat experiments. The samples were taken from covered chest, covered arm, covered leg and bare leg.

The averages here bring out two quite interesting points. In the first place it will be noted from this set of experiments that there is a regional

TABLE 3

HEAT SWEAT pH VALUES		WORK SWEAT pH VALUES	
Covered arm	Covered leg	Covered arm	Covered leg
5.7	5.2	5.7	5.5
5.3	5.7	6.0	5.8
5.2	5.0	5.6	5.5
5.3	5.1	5.0	4.8
5.7	5.5	5.4	5.3
5.8	5.7	5.7	5.4
5.8	5.6		
5.8	5.6		
5.75	5.3		
5.45	5.3		
4.95	4.85		
5.8	5.6		
5.7	5.5		
5.8	5.6		
5.5 av.	5.39 av.	5.58 av.	5.39 av.

TABLE 4

HEAT SWEAT pH VALUES		WORK SWEAT pH VALUES	
Bare face	Covered chest	Bare face	Covered chest
6.5	6.1	6.6	6.2
6.1	5.6	6.1	5.5
5.6	5.4	6.0	5.2
5.7	5.3	6.1	5.5
5.7	5.3	5.9	5.7
5.9	5.9	6.2	6.0
6.0	5.8	6.0	5.8
6.1	5.85	5.7	5.5
6.2	5.85		
5.99 av.	5.68 av.	6.07 av.	5.55 av.

TABLE 5

HEAT SWEAT pH VALUES			
Covered chest	Covered arm	Covered leg	Bare leg
5.8	5.75	5.3	5.8
5.6	5.45	5.3	5.8
5.5	4.95	4.85	5.35
5.6	5.45	5.3	5.8
5.8	5.7	5.5	5.9
5.7	5.6	5.4	5.7
5.9	5.7	5.3	5.8
5.8	5.7	5.4	5.75
5.8 av.	5.54 av.	5.26 av.	5.73 av.

variation, as is shown by the highest hydrogen ions from the covered leg, this is followed by the arm and with it a fairly close agreement in the chest, while the lowest acidity comes from the bare leg.

The second point to be noted is the difference in the acidity of the covered and the bare leg, which furnishes an illustration of a well-controlled experiment as the sweat from both legs was collected simultaneously.

The same two points are developed in table 1, with the exception that the covered chest and covered arm run very close in their averages, which are 5.72 and 5.71 respectively.

In this instance the bare face, as the exposed part of the body, gave a lower hydrogen ion.

It seems to me these experiments solve the problem. They show why in my earlier observations I obtained higher hydrogen ions from the heat sweat. The results were not due to the sweat being more acid when secreted, but they were more than likely due to the fact that when the subject was enclosed in a cabinet with much humidity and poor ventilation, there was a hindrance to the volatilization of the acid-producing substances in the sweat, which, on the contrary, would take place more easily when the subject is riding on a bicycle with the skin exposed directly to a normal atmosphere.

That there are such volatile substances I am well convinced, as I had reported in my former paper (11).

This showed there were two possible factors to cause this acidity: Either we were dealing with CO_2 or volatile organic acids, or possibly both.

It seemed at first that CO_2 might be a factor, as it is generally agreed that more or less of this gas is being eliminated by the skin. The amount reported has been quite variable in the hands of different investigators. I undertook, however, a series of experiments for the purpose of testing the CO_2 content of the sweat by the Van Slyke method. The collecting tubes in each instance were quickly stoppered after the mouth was withdrawn from the collecting troughs and remained so until ready for the tests, which were made as soon as possible. My results showed that CO_2 was quite a negligible factor.

In all of my testing for the hydrogen ions the test-tubes were freely exposed to the air, so that the CO_2 equilibrium would soon take place, but notwithstanding this fact the acidity of the sweat remained quite the same after hours of such exposure.

After boiling some sweat Kittsteiner claimed that instead of a decrease in acidity he had found, on the contrary, an increase, which certainly throws CO_2 out of the reckoning.

With these results I am thoroughly convinced that the volatile organic acids are at least a factor in the acidity of the sweat. Whether they are the all important factor I am not, at present, prepared to say.

Unna (12) claims that formic, acetic, propionic, butyric and caproic acids may be found.

In the middle of the nineteenth century, Favre believed he had found lactic and what he called hidrotique acid. As to the former, I made some twenty tests with negligible results.

Conclusions. As to the general effect of the rubber jackets, my data show quite definitely that they had a tendency to raise the hydrogen ions of the work sweat rather than to lower them in the heat sweat.

In 53 heat sweat experiments while the subjects were naked in the cabinet, a pH average of 5.73 was obtained, while in 46 experiments enclosed in rubber jackets the heat sweat gave an average of 5.64. These averages are fairly close for so many experiments. On the other hand, 53 work experiments with the naked body gave a pH average of 6.22, while in 28 work experiments with rubber jackets the pH average was 5.65.

This is as we would naturally expect, for the difference in the environmental conditions was much more marked in the two sets of work experiments than in the two sets of heat experiments.

Perhaps what is still more convincing is the grand average of all work experiments with rubber jackets, which gave a pH of 5.65, and likewise all of the heat experiments with the jackets yielded a grand total of pH 5.64.

While it may be true as maintained by Kittsteiner that the higher the temperature under which sweat is produced the higher the acidity, so it may be that the heat is a contributing factor to the higher hydrogen ion value obtained from heat sweat in my earlier experiments. It does not mean that if the heat and work sweat are produced under the same atmospheric conditions there would be any disparity in the hydrogen ions. As a matter of fact, in the data that I am reporting in this article where the parts of the body were enclosed, it appears quite to the contrary. Furthermore, I found on several occasions when the room temperature was quite alike the two kinds of sweating produced about the same averages. Further work may throw additional light on the subject.

The statement which is so often found in the texts, that the acid reaction of the sweat is secondarily due to the fatty decomposition of the sebum, is rather unwarranted or at least is lacking in substantial support.

As to the regional variations, my results are quite contrary to those reported by Kittsteiner in which he speaks of the arms as the most acid, then followed by the face, while the leg was almost constantly neutral. In all my experiments where arm and leg were enclosed, the latter yielded the higher hydrogen ions.

SUMMARY

1. When sweat is secreted under the same environmental conditions, except temperature, the work and heat sweat gave the same hydrogen ions.

2. The sweat collected from the skin covered with a rubber jacket yielded higher hydrogen ions because there is not quite the freedom for the escape of the volatile organic acids.

3. There is a regional variation in the amount of acid eliminated by the sweat glands which is difficult to explain.

I wish to take this opportunity to convey my sincere thanks to Professor Carlson for his helpful suggestions and kindly interest.

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THE ASH OF HUMAN SWEAT PRODUCED BY HEAT AND WORK

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Upon the examination of the literature I have found that scarcely any work has been done on the determination of the ash of the sweat. Smith (1) and Pugliesse (2) have given us reports on the ash from the horse, while Camerer (3) seems to stand quite alone as far as any such work has been done on man. Even his work has been confined to sweat produced by heat. Pugliesse, however, studied both heat and work sweat of the horse. As far as determining the constituents of work sweat of man is concerned, this seems to have been first attempted by Cohnheim and Kreglinger (6) and later by Viale (4), who confined themselves to sodium chloride elimination. The latter was the first to make a comparison of the human heat and work sweat.

Favre (5) found that of the inorganic substances the chlorides furnished by far the largest amount, particularly the sodium chloride, while the sulphates were exceedingly small and the phosphates were only a trace. So any important fluctuations in the ash could be reasonably attributed to the sodium chloride.

As far as I have been able to discover, no work has been done on the ash of the human work sweat. My purpose then was to compare the ash produced from work with that produced from heat under the same environmental conditions, as far as possible, with the exception of temperature. So for that purpose I employed the same rubber jackets for the chest, arm and leg as were used in collecting the sweat for acid determinations (11). In a similar manner the stationary bicycle and the sweat cabinet were employed for producing work and heat sweat respectively.

Methods. In my experiments I used either new or thoroughly cleaned porcelain crucibles which with their covers were heated and weighed, then the operation was repeated until no loss of weight could be detected. These crucibles were then kept in desiccators until time to receive the sweat.

Into these crucibles 10 cc. of filtered sweat were accurately pipetted and weighed. After deduction of the weight of crucible it would give the weight of this amount of sweat, which being compared with an equal volume of distilled water, with temperature correction, would give a difference that would represent the total solids. The sweat was then evaporated over a water bath and subsequently ashed with the usual precautions.

Heat and work sweat. I performed twenty experiments, ten of which were samples taken from heat sweating and ten from work sweating. In table 1 there was an average ash of 0.337 per cent from heat sweat and 0.443 per cent from work sweat. These results are quite in harmony with the determinations of Pugliesse on the horse. They also accord very well with the results obtained by Viale on the sodium chloride content of man in comparing heat and work sweat. The latter claimed that there was a gradual increase in this salt as the work progresses, and in fatigue he has found as high as 0.85 per cent, while in two heat experiments he obtained as low as 0.154 per cent and 0.135 per cent respectively.

Camerer claimed to have found from electric light bath a sodium chloride content as high as 0.66 per cent, hot air bath 0.78 per cent, and a vapor bath of only 0.465 per cent. These figures seem high when compared with my ash determinations. However, my figures are not so far from those obtained by him in the vapor bath. In fact, the conditions under which sweat was secreted under a rubber jacket would be much like a vapor bath.

In connection with the increase of sodium chloride in the sweat as a result of long marches on a mountain, Cohnheim and Kreglinger (6) have spoken of an enormous diminution of the salt in the urine on the following day, and again when sweating is profuse on a march, the gastric juice may be deprived of its hydrochloric acid.

Cohnheim, Weber, Kreglinger and Tobler (7) state that the loss of weight which frequently follows a fatiguing march may be quickly compensated for if a chloride diet is given. Which proves that in fatigue there is a general chloride insufficiency in the organism.

It is well to note on the contrary Ardin-Delteil (12) has discovered that in heat sweating there is a progressive diminution in NaCl content. Also Tarugi and Tomassi (13), who provoked a profuse sweating, found that the viscosity and molecular concentration diminished in the time in which the sweat was emitted under the action of heat.

With the increasing elimination of sodium chloride from the sweat glands in fatigue, the question naturally arises as to the state of the blood and tissues, especially the muscles under these conditions. Unfortunately, on this point there has not been an entire unanimity of opinion.

Rogozinsky (5) tells us that the physical and chemical properties of the blood do not change, but the muscles, on the other hand, lose water as a result of work.

Buglia (9) reports that the molecular concentration of the blood undergoes a slight increase, while the electric conductivity remains the same in fatigue, while in the muscles the osmotic concentration diminishes as the conductivity diminishes.

Gerhartz (10) found a diminution of water in the blood as a result of prolonged work, also an increase in specific gravity, hemoglobin and nitrogen, while in muscles less water and less mineral substances.

On the other hand, Cohnheim, Kreglinger, Tobler and Weber found as a result of fatigue on Mt. Rosa at 3000 meters a diminution of red corpuscles and hemoglobin. Viale in two experiments confirmed their results.

Here we have a fairly good agreement as to changes brought about in the muscles, but widely divergent as to the blood as result of work.

It seems quite certain that there is a depletion of the water reserve and also of the NaCl in the tissues. As to the former, it may be assumed that the loss of water to the muscles is due to the requisition of the sweat glands and the latter are stimulated by the heat produced from the metabolism of the muscles. We have no assumption that the increased salt elimination is directly due to the metabolism. On the contrary, it may be assumed the increased water output acts as a vehicle in removing more salt.

It is difficult to put an interpretation on the wide variance in their results on the blood.

It seems to me the problem is too complicated to do much theorizing in the light of our present knowledge. This much might be said, however, while there might be a temporary dilution of the blood at a certain stage of the activity of the muscles, yet, on the contrary, it seems more reasonable that in a long-continued fatigue, and provided there is no intake of water, there would be such an exhaustion of the water from the tissues for the purpose of heat regulation as to cause a concentration of the blood.

As to the increased of NaCl in work sweat we may find part of our solution in the decrease of the salt in the urine, and also of the HCl in the gastric juice as determined by Cohnheim and Kreglinger. Furthermore, part of the concentration can likely be laid to the fact of the increased respiration which would have a tendency to carry away more water through the lungs.

Regional variations. One of the most interesting points developed in the study of the ash is the regional variations on the covered parts of the body.

In table 2, comparing the sweat which was taken simultaneously from covered arm and covered leg, the former shows an average of 0.375 per cent of ash, and the latter shows an average of 0.262 per cent. In the third column the bare leg yields 0.219 per cent.

Similar results are noted in table 3. In this case, however, the sweat was collected from only two parts of the body.

In table 4 the covered arm and covered chest are compared in like manner. Here the covered arm gave an average ash of 0.356 per cent, while the chest was 0.438 per cent.

In table 5 the average ash from the bare chest and from the covered leg were compared. The former yielded an average ash of 0.368 per cent, the latter 0.234 per cent.

Comparison of naked and covered skin. Another point of interest is the difference in the amount of ash obtained from the naked parts compared with the covered parts. In table 2 eight experiments were with the covered leg and bare leg, and it will be noted without exception that the former gave the greater ash. The same point is brought out in table 6, where we compare the covered chest with the bare chest. These samples could not be obtained by simultaneous sweating like that of the leg. However, the differences in the averages are so great that the comparisons become quite as convincing. So it is observed that with corresponding parts of the body the covered portion gives a greater ash than the naked.

In table 5, when comparing different parts of the body, as bare chest and covered leg, we observe that the regional factor may predominate, as seen here where the ash average for the bare chest is 0.368 per cent, while covered leg is 0.234 per cent.

It is of interest to note that the parts of the body that eliminate the most acid yield the smallest ash in the sweat. Particularly is this true of the leg. The chest as a rule eliminates the smallest amount of acid and the greatest amount of ash when the parts are covered. However,

the difference in the acidity of the arm and chest is not as marked as the difference in the ash.

The results that we have obtained from the covered parts over against the uncovered are different from what we would naturally expect. We would with some reason suppose that there would be a condensation of the insensible perspiration under the jackets which would have a tendency to dilute the sensible perspiration.

Professor Carlson suggested that the skin temperature might be an important factor in raising the salt content of covered parts. To that end I tried out a series of experiments on myself. I chose two hot July afternoons with a room which allowed the full rays of the sun. I stripped off all clothing and lay on my back on a bed and tested the skin temperature with ordinary clinical thermometers comparing particularly covered and uncovered parts simultaneously, also choosing parts of the body where it was possible to cover the bulbs of the thermometers completely to the exclusion of the air. For this purpose I chose the popliteal space, the antecubital, the axilla and the abdomen. In the last named position the thermometers were imbedded in the creases of the skin produced by bending forward. Thermometers were standardized before using and the room temperature varied from 105° to 108°F. Mouth temperature was 99°F.

In table 7 are the comparative temperatures in the popliteal region taken simultaneously from the covered leg and the bare leg. Each test lasted ten minutes. Here will be found a higher temperature of 0.5°F. with the covered leg. Test of space at the antecubital was taken at the same time. The covered arm and covered leg run practically the same. The first five experiments were performed on one day and the last five the next day.

In table 8 similar tests were tried at the antecubital fossa with the same general results except that the differences were not so marked. Likewise, the results in table 9. In table 10 we found that the differences were even more pronounced than from the leg.

I offer this data as a possible factor in increasing the salt secretions on the covered parts.

SERIES I

TABLE 1

Ash from covered chest

HEAT SWEAT	WORK SWEAT
<i>per cent</i>	<i>per cent</i>
0.306	0.433
0.301	0.491
0.310	0.407
0.317	0.400
0.541	0.691
0.380	0.370
0.291	0.410
0.366	0.301
0.298	0.420
0.388	0.500
0.337 Av.	0.443 Av.

TABLE 3

COVERED ARM	COVERED LEG
<i>per cent</i>	<i>per cent</i>
0.537	0.264
0.354	0.297
0.345	0.259
0.324	0.208
0.439	0.288
0.325	0.225
0.387 Av.	0.273 Av.

TABLE 5

BARE CHEST	COVERED LEG
<i>per cent</i>	<i>per cent</i>
0.318	0.203
0.363	0.243
0.422	0.255
0.368 Av.	0.234

TABLE 2

COVERED ARM	COVERED LEG	BARE LEG
<i>per cent</i>	<i>per cent</i>	<i>per cent</i>
0.537	0.264	0.232
0.354	0.297	0.364
0.343	0.310	0.210
0.324	0.259	0.184
0.439	0.208	0.204
0.325	0.288	0.239
0.266	0.203	0.190
0.343	0.270	0.220
0.375	0.262	0.219

TABLE 4

COVERED ARM	COVERED CHEST
<i>per cent</i>	<i>per cent</i>
0.324	0.433
0.367	0.491
0.384	0.407
0.309	0.400
0.511	0.691
0.307	0.370
0.358	0.410
0.290	0.301
0.356 Av.	0.438 Av.

TABLE 6

COVERED CHEST	BARE CHEST
<i>per cent</i>	<i>per cent</i>
0.433	0.318
0.491	0.363
0.407	0.422
0.400	0.354
0.691	0.365
0.370	
0.401	
0.301	
0.438	0.364

SERIES II

TABLE 7

Popliteal skin, temperature, Fahrenheit scale

	COVERED LEG	BARE LEG	COVERED ARM
First day ...	97.5°	97.5°	
	98.2°	97.4°	98.3°
	98.2°	97.4°	98.3°
	98.3°	97.4°	98.3°
	98.3°	97.3°	98.3°
Second day....	98.7°	98.4°	
	98.8°	97.0°	
	97.9°	96.9°	97.8°
	97.8°	96.8°	97.8°
	97.8°	96.8°	98.0°

TABLE 9

Axillary skin temperature, Fahrenheit scale

COVERED ARM	BARE ARM
98.6°	98.0°
98.7°	98.3°
98.7°	98.3°

TABLE 8

Antecubital temperature, Fahrenheit scale

COVERED ARM	BARE ARM
97.8°	97.5°
98.8°	97.6°
98.5°	98.2°
98.6°	98.4°
98.6°	98.4°

TABLE 10

Abdominal skin temperature, Fahrenheit scale

COVERED ABDOMEN	BARE ABDOMEN
98.4°	96.8°
98.2°	97.3°
98.2°	96.7°
98.2°	97.3°
98.2°	97.3°

SUMMARY

1. There is a greater amount of ash in work sweat than in heat sweat.
2. There is a regional variation in the ash where the parts are covered, smallest percentage from the leg, then followed by the arm, while the largest comes from the chest.
3. There is a greater ash from the sweat of covered parts than corresponding naked parts.
4. The concentration of the salts in the sweat glands is in part a function of the temperature of these glands. The higher the temperature, the greater the concentration of the salts.

I wish in this connection to thank Professor Carlson for the inspiration and helpful suggestions received.

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